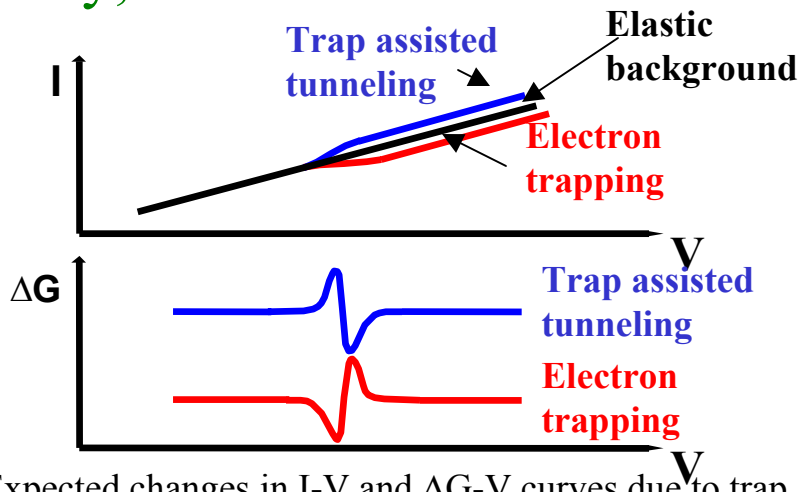
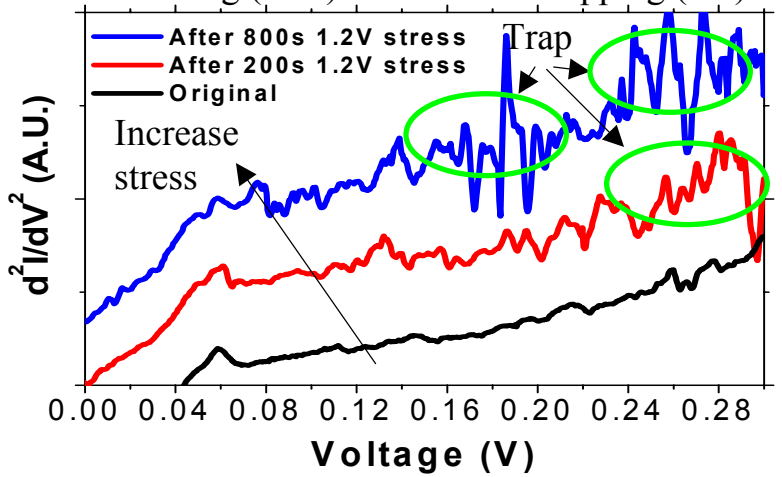
Inelastic Electron Tunneling Spectroscopy (IETS) Study of High-K Gate Dielectrics

T.P.Ma, Yale University, DMR-0096762

The ability to scale down the gate dielectric in CMOS transistors is a key to sustain the exponential growth of the Si-based semiconductor industry. However, the traditional gate dielectri, SiO_2, has now been shrunk down to thinner than 2.0 nm of SiO_2, and in a few years it will be so thin that the leakage current through it will render the circuit useless. Therefore, there is a pressing need to find a alternative gate dielectric that has much lower leakage current. The most promising alternative dielectrics are those metal-oxides that have high dielectric constants, the so-called high-k dielectrics, including HfO_2, ZrO_2, and La_2O_3. This project uses electron tunneling as a probe to study the bonding structure, defects, and impurities in ultra-thin (< 2nm) high-k dielectrics on Si. The electron tunneling probe is more advantageous than many conventional thin-film spectroscopy tools (such as IR, Roman, and neutron spectroscopy) because the sensitivities of the latter diminish as the film thickness decreases, while the former becomes **more** sensitive as film thickness decreases, which is in the direction of CMOS scaling trend. The figures here show that the IETS spectra can reveal valuable information about electronic traps in high-k dielectrics.



Expected changes in I-V and ΔG-V curves due to trap assisted tunneling (blue) and electron trapping (red)



Measured ΔG-V curves exhibit features of electronic traps in HfO_2 generated by electric stress

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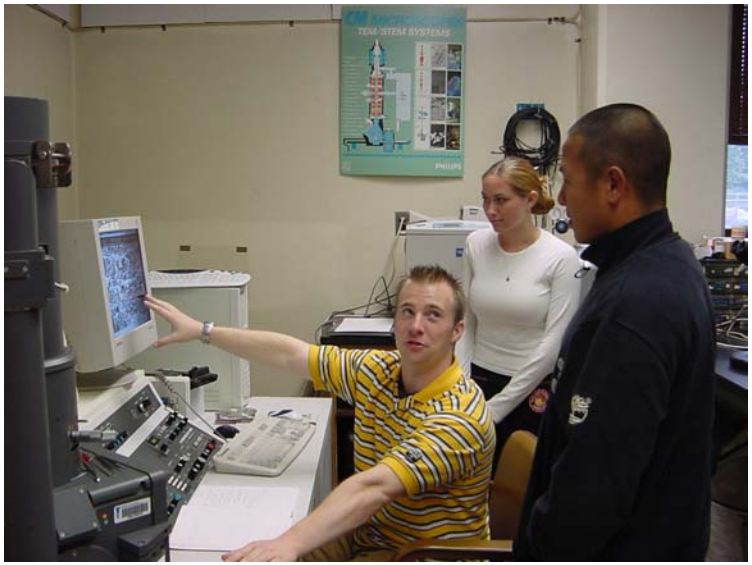
Education and Outreach:

Two graduate students (Wei He and Wendy Zhu) were the primary participants in the research. Zhu received her Ph.D. in the spring of 2003 and is presently a research scientist at IBM. The PI developed a collaboration with a nearby undergraduate institution (Christine Broadbridge at Southern Connecticut State Univ). Through the resulting SCSU-Yale outreach initiative, three SCSU undergraduates (Daniel Pechkis, Jacquelynn McGuinness and Ryan Fitzsimmons) participated in the research. Pechkis received a Microscopy Society of America Scholarship for his work before graduating and entering the Ph. D. program at William and Mary. Additionally, the research is now used for the preparation of future teachers as well as New Haven K-12 outreach.



McGuinness and Fitzsimmons (shown above) are using their research experience to mentor New Haven area middle and high school students. Future teacher Fitzsimmons is also using microscopy research techniques to develop 8-12 teaching modules for use in the classroom.